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PACKET FORMATS FOR MEASUREMENT EXPERIMENTS

The purpose of this note is to summarize design plans for a variable length packet format. This format will be used in the propagation and noise measurements to be conducted this fall. The note discusses the general constraints and design parameters considered during the packet format design and the reasoning which led to these particular formats.

We note that these formats are not considered necessarily realistic nor appropriate for a functioning radio network. Rather, they are to enable the measurement experiments to collect the data necessary for rationally choosing appropriate formats.

Attempts have been made to include considerations for a routing scheme proposed by N.A.C. (Packet Radio Temporary Note #52) and to accommodate different acknowledgement schemes, different length error detection codes (EDC), different packet synchronization patterns, and to minimize hardware interface tasks. Special consideration has been given to defining the format in such a manner that format changes can be effected with minimum, if any, changes in the hardware interface.

This document will be a preliminary design specification for the hardware interfaces used in the measurement experiments.

1. INTRODUCTION

At this time, no firm decisions have been, or can be, made regarding many network protocol features, e.g. routing, acknowledgement schemes, device identification, and character echoing. In addition, decisions regarding r.f. frequencies, data rates, and packet lengths must be considered preliminary inasmuch as the r.f. characteristics of the radio channel are not well defined.

In fact, it is the purpose of the measurement program to analyze the channel characteristics in terms of noise, propagation, and data rates. To conduct these measurements it is planned to fabricate an experimental packet transmission and receiving system organized around one or several minicomputer(s).

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The packet formats directly affect the hardware schemes used to fabricate the experimental system. To connect the r.f. equipment to the minicomputer(s) it is necessary to construct a special purpose digital interface. Clearly, the interface is dependent upon packet format, bit positions and their settings, and field lengths. While it is possible to define a fixed set of packet formats and build the necessary interface, such activities will inevitably lead to costly and time consuming interface revisions during the experiments. This is due to the fact that we have no basis upon which to assume that the packet selections are sub-optimal, let alone optimal. Thus, it was considered judicious for the purposes of the measurement experiments to select a packet format where both the header and message segments are of variable length.

The following discussions are organized around the variable length packet, r.f. interface implications, error detection codes, routing efficiency, packet efficiency, and packet fields. Specific discussions concerning such topics as acknowledgement schemes and packet types are included in the discussion of packet fields.

2. VARIABLE LENGTH PACKETS

The variable length packet satisfies many design constraints and accommodates:

- Variable length messages and their relationship to noise and multipath effects,
- Optional routing schemes with differing numbers of bits,
- Different error detection code lengths and subsequent noise dependence,
- Optional header bits for numerous studies, and
- Ability to build hardware interfaces that will require nominal, if any, changes in the r.f. interface as the format is modified.

The last point is important. It is our intention to build an interface that will interrogate the same control bits and length fields while allowing the other packet fields to be used in any manner necessary for the experiments. Of course, certain functions that will be performed eventually in a production interface, e.g. address checking and routing, will have to be performed initially in a minicomputer. In some cases a minicomputer may not have the speeds necessary to perform such functions at high data rates. However, we feel minicomputers will adequately support the measurement experiments. Once conclusive decisions regarding packet format and length can be reached, subsequent experiments will be conducted in which address checking and packet routing are performed directly in the interface.

The packet format is displayed in Figure 1.

Pkt Fmt	Cntrl Bits	Header Length	Header Field*	Header EDC*	Message Length	Message Field*	Message EDC*
0	1	4	8				

----------Short Packet----------
------------------------------Long Packet------------------------

* Indicates a variable length field

Figure 1. General Variable Length Packet Format

The following comments are pertinent to Figure 1:

- the packet synchronization pattern is unspecified at this time.
- the packet format field is a single bit, interrogated by the interface, that specifies a short or long packet.
- the control bits are discussed in subsequent sections. At this time they are not intended to be recognized by the interface.
- the header length is a four-bit field that specifies the length of the header field in characters (maximum length = 2**4-1 = 15 characters = 120 bits), which enables the interface to:
  a) locate the header error detection bits, and
  b) determine one of two header error detection code lengths (see discussion on Error Detection).
- the message length is an 8-bit field that specifies the length of the message field in characters (maximum length = 2**8-1 = 255 characters = 2040 bits), which enables the interface to:
  a) locate the message error detection bits, and
  b) determine one of three message error detection lengths (see discussions on Error Detection). Of course, the existence of this field implies the format field bit is set indicating a long packet.

Based upon this design we will build a digital logic interface that interrogates the bits and fields discussed above. This allows the other bits within the header and message fields to be revised, increased or decreased in length, or redefined without any changes required in the interface.

3. ERROR DETECTION CODES

The absence of detailed noise characteristics of the channel make it difficult to postulate appropriate error detection code requirements.

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The lack of definitive data on packet length also makes difficult the specification of necessary error detection code length. We have specified several lengths for both header and message text to accommodate attempts to minimize the effects of noise bursts of unknown duration. Table 1 illustrates the proposed implementation.

TABLE 1. PACKET ERROR DETECTION LENGTHS

HEADER SEGMENT		
Header Length Bit Settings	Number of Characters in Header Field	EDC Length in Bits
0XXX	0-7	8
1XXX	8-15	16

MESSAGE SEGMENT		
Message Length Bit Settings	Number of Characters in Message Field	EDC Length in Bits
00XXXXXX	00-63	16
01XXXXXX	64-127	24
1XXXXXXX	128-255	32

There is some concern that an eight-bit header error detection code may not be adequate. Consequently, we may elect to use the most significant bit in the header length to specify a fixed-length sixteen-bit header error detection code. This bit should be available since it is unlikely that the header field exclusively will exceed three bits in length (i.e. seven characters = fifty-six bits). Similar options exist in the message fields.

Table 2 reflects the basic variations in packet lengths and error detection codes that are possible.

TABLE 2. ILLUSTRATIVE PACKET FORMATS

HEADER					MESSAGE		
Pkt Fmt	Cntrl Bits	Length Bits	Field Bytes	EDC Bits	Length Bits	Field Bytes	EDC Bits
0	XXX	0XXX	0-7	8	N/A	N/A	N/A
1	XXX	0XXX	0-7	8	00XXXXXX	0-63	16
1	XXX	0XXX	0-7	8	01XXXXXX	64-127	24
1	XXX	0XXX	0-7	8	1XXXXXXX	128-255	32
0	XXX	1XXX	8-15	16	N/A	N/A	N/A
1	XXX	1XXX	8-15	16	00XXXXXX	0-63	16
1	XXX	1XXX	8-15	16	01XXXXXX	64-127	24
1	XXX	1XXX	8-15	16	1XXXXXXX	128-255	32

4. ROUTING AND PACKET EFFICIENCY

As mentioned earlier, provisions have been made in the packet format to accommodate a variation of the N.A.C. routing scheme*. This is accomplished by dividing a portion of the header field into several subfields and defining the necessary bits for terminal, repeater, and station identification.

Figure 2 illustrates a representative header field that includes bits for routing of terminal-repeater-station communications. We note that provisions for terminal-terminal communications are provided by the host computer when the target terminal identification is introduced as text in the message.

Packet Type	Station ID	Level	Repeater IDs	Terminal Flag	Terminal ID	Info Byte
8	11	13	16	37	38	48

Figure 2. Header Field with Routing

The following comments are pertinent to Figure 2.

- Packet type, a three-bit field, is discussed in subsequent sections.
- Bits 11-47 are identification and routing bits used as follows:
  - Station ID - a two-bit field used to identify a unique station in the event the transmission can be directed to, or heard by, more than one station. Thus, up to three (values 0-2) unique stations may be accommodated. If the field contains a three (3), then the packet is being broadcast to any station that hears it.
  - Level - a three-bit field used to specify the depth of a packet as it moves within a repeater network. For example, a packet transmitted from a repeater at

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* Note that the N.A.C. maximum handover number for lateral transfers at the same repeater level within the network is not included in this format.

level 6 to a repeater at level 5 would have a value of five (5) in this field. On subsequent transmission to the next repeater level toward the station, this field would be decremented to a value of four (4). The minimum value of zero (0) specifies the station level, while the remaining values (1-7) specify the different device levels.

- Repeater IDs - a series of seven three-bit subfields that designate the path the packet will take through the repeater network. The value of the three-bit subfield indexed by the current value of level identifies a unique repeater within a given level. Up to six (6) repeaters in each level are accommodated since the values zero (0) and seven (7) are reserved for special functions. The value zero (0) designates that the terminal is linked to a repeater located in the level specified by the current value of the LEVEL field. Moreover, if the seventh repeater ID has a non-zero value it is also assumed that the terminal is linked to that repeater. The value seven (7) designates an open broadcast to any repeater located in the level specified by the current value of the LEVEL field.

The maximum number of repeaters that can be accommodated is thus:

Number of stations	x	Number of levels below station	x	Number of repeaters per level		
3	x	7	x	6	=	126

An effective repeater address can be generated in several ways. For example, in terminal-station communications the pertinent fields are:

Station ID Level R(1),R(2),...,(R7)

By defining the effective address of each repeater in the following manner,

Station ID Level R(Level)

we could generate the address by treating the contents of LEVEL as an index to select the three-bit subfield from the twenty-four bit repeater ID field. Another method would shift circularly the repeater ID field a single subfield width and decrement the LEVEL field so that the effective address is formed by the same field bits, e.g. linking from

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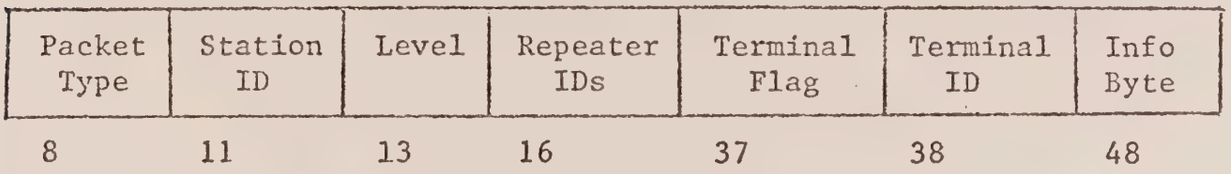

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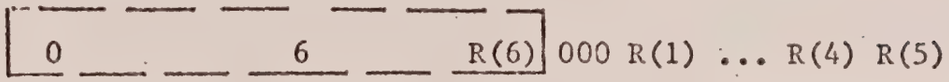
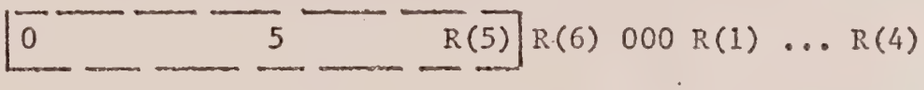
the terminal to the sixth level repeater would appear:



Upon processing by the 6th level repeater, the re-transmitted packet would look like:



Another option would be to rotate the repeater ID field the number of subfields less one specified in the LEVEL field. However, this would introduce a variable amount of work (and possibly delay) in the interface at each repeater level since the shift time depends on the level depth. In any event, when such effects are studied in the measurement experiments, they will be simulated in the minicomputer(s).

Referring to Figure 2, we have the following additional comments:

- Terminal Flag - a one-bit field that specifies that a packet is being transmitted from a repeater at a given level to a terminal linked to it rather than another repeater on the same repeater level.

- Terminal ID - a ten-bit field that identifies up to 1023 unique terminals. The maximum value (1023) designates a packet being broadcast to any terminal. Since we use the repeater subfield value of zero (0) to indicate the level to which the terminal is linked, the effective number of terminals could be 1023 per level. However, such a scheme would not accommodate mobile terminals. In such an event, the maximum number of unique terminals for an entire network in a given geographical location would be 2**10-1 = 1023.

- Info Byte - Provisions are made for carrying one character of text in the header, or, in the event of a control packet, this field contains one of two hundred fifty six (256) unique control messages.

It is interesting to study the relationship of the efficiency of transmitted packets vs. the number of message characters transmitted within the total packet. We define the packet efficiency E as:

$$E = \frac{\text{number of text message bits sent}}{\text{number of packet bits sent}}$$

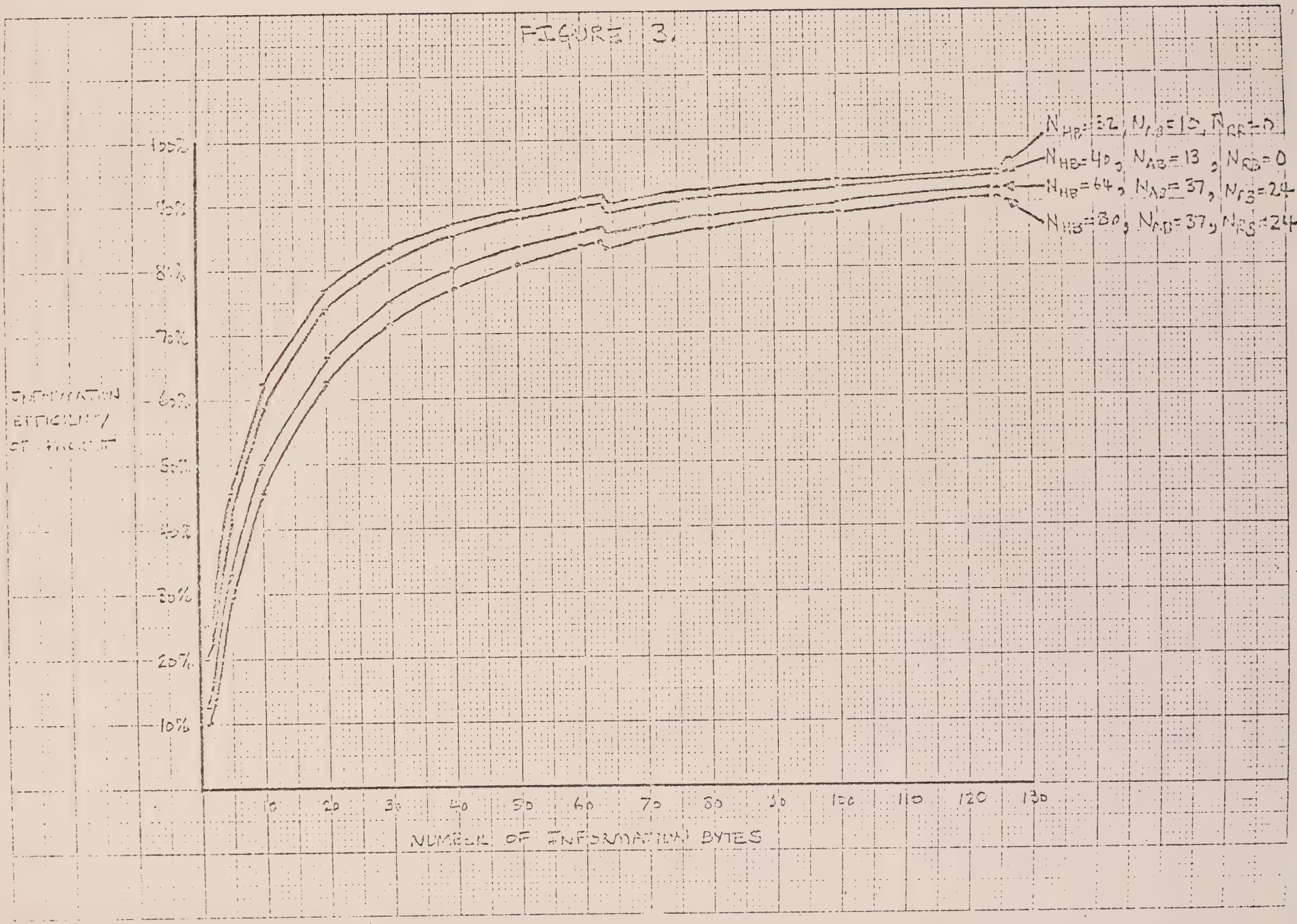


FIGURE 3.
$N_{HB}=52$, $N_{AB}=10$, $N_{RB}=0$
$N_{HB}=40$, $N_{AB}=13$, $N_{RB}=0$
$N_{HB}=64$, $N_{AB}=37$, $N_{RB}=24$
$N_{HB}=80$, $N_{AB}=37$, $N_{RB}=24$
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
10
20
30
40
50
60
70
80
90
100
110
120
130
NUMBER OF INFORMATION BYTES

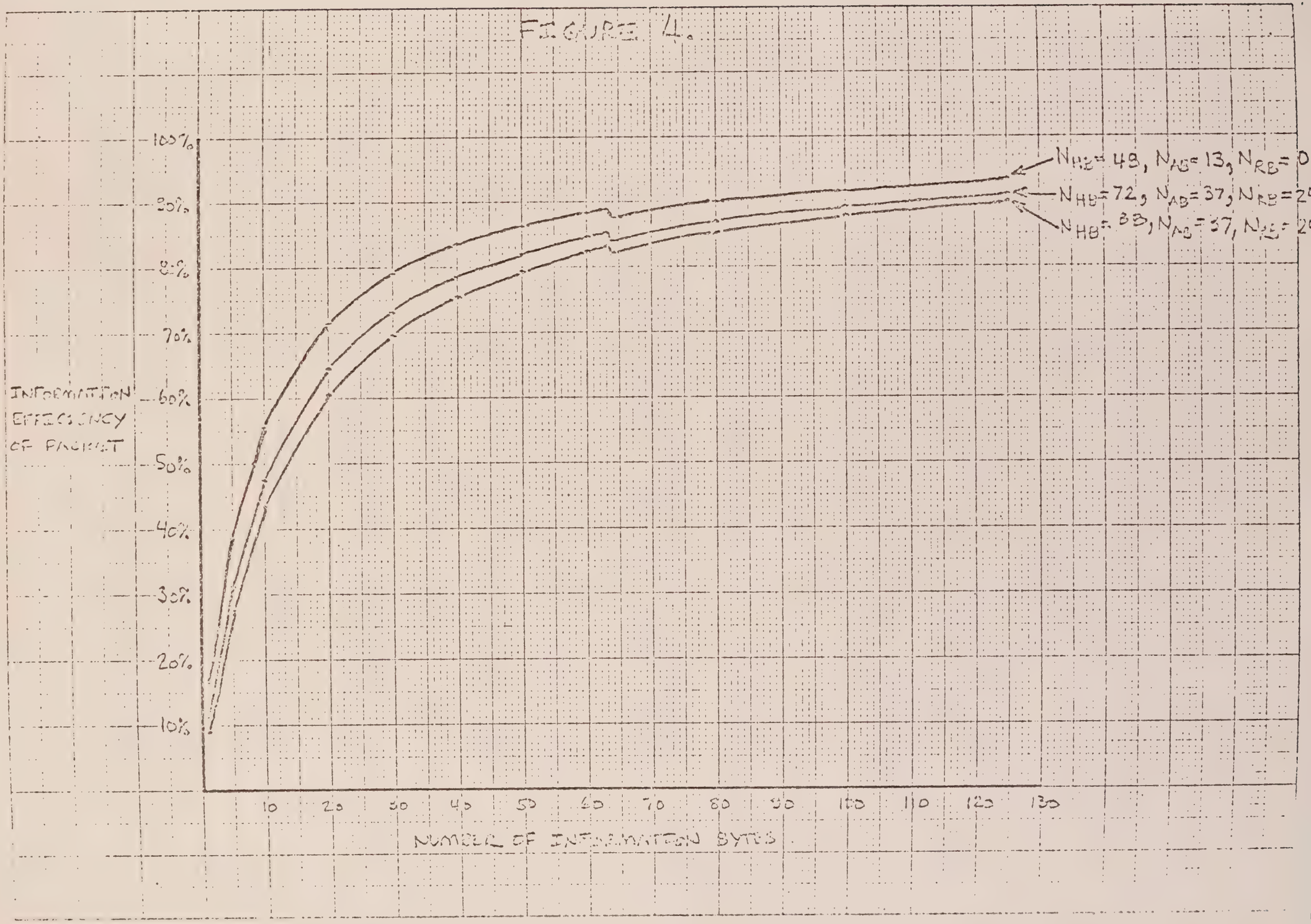


FIGURE 4.
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
INFORMATION EFFICIENCY OF PACKET
N_{HB}= 48, N_{AB}= 13, N_{RB}= 0
N_{HB}= 72, N_{AB}= 37, N_{RB}= 2
N_{HB}= 88, N_{AB}= 37, N_{RB}= 2
10 20 30 40 50 60 70 80 90 100 110 120 130
NUMBER OF INFORMATION BYTES

Figures 3 and 4 plot the values of E as the number of text bytes are varied from 1 to 125 (8 to 1000 bits). For convenience, control packets can be considered one byte messages. Figure 3 shows the variation for cases with and without the use of routing bits and eight bits of header error detection code. Figure 4 shows the variation for those packets with sixteen-bit header error detection fields. Note that twenty-four bits are included for routing, a length that represents both the LEVEL and repeater ID fields. The step function deviations in the curves are caused by an incremental step in message error detection code as the message length increases from 63 to 64+ characters.

Ignoring noise and interface considerations, these graphs show that short packets are particularly inefficient while packets greater than eighty (80) characters offer relatively few gains in information efficiency. The use of routing bits for short packets is extremely inefficient while the penalty decreases rapidly after the packets exceed ten (10) characters. It is clear from this analysis that acknowledgement packets must be short or they will place an unusually heavy burden on the network.

5. PACKET FIELDS

The entire packet format is displayed in Figure 5. The following discussion is pertinent:

- The packet synchronization field is undefined. However, we can postulate a pattern similar to the ALOHA system, where a series of zero bits followed by a single bit of one triggers the start of packet

- The packet format field specifies short (header only) or long (header and message) packet

- The packet new field indicates that the packet is new or re-transmitted and is similar to the ALOHA and ARPANET ALT bit.

- The packet last field designates the last packet in a message.

- The packet direction field determines whether the packet is directed towards the station or a terminal and specifies the manner in which the routing address is determined or revised for subsequent re-transmission.

- The header length is discussed earlier. (We note that this field could be re-used in the production packet format for measurement and diagnostic bits.)

- The packet type is a three-bit field that describes the type of packet, (e.g. text, control, ACK, NAK, etc). Note: An acknowledgement packet format is yet to be defined. However, it could be accommodated with a unique form of header packet. The high number of routing bits tend to make the hop-to-hop acknowledgement scheme extremely inefficient.

- The station ID, packet level, repeater ID, terminal flag, and terminal ID fields are discussed earlier.
- The info byte field is included in the header for use as a text character or for specifying up to 256 unique control packets.
- The rest of the fields are discussed in earlier sections.

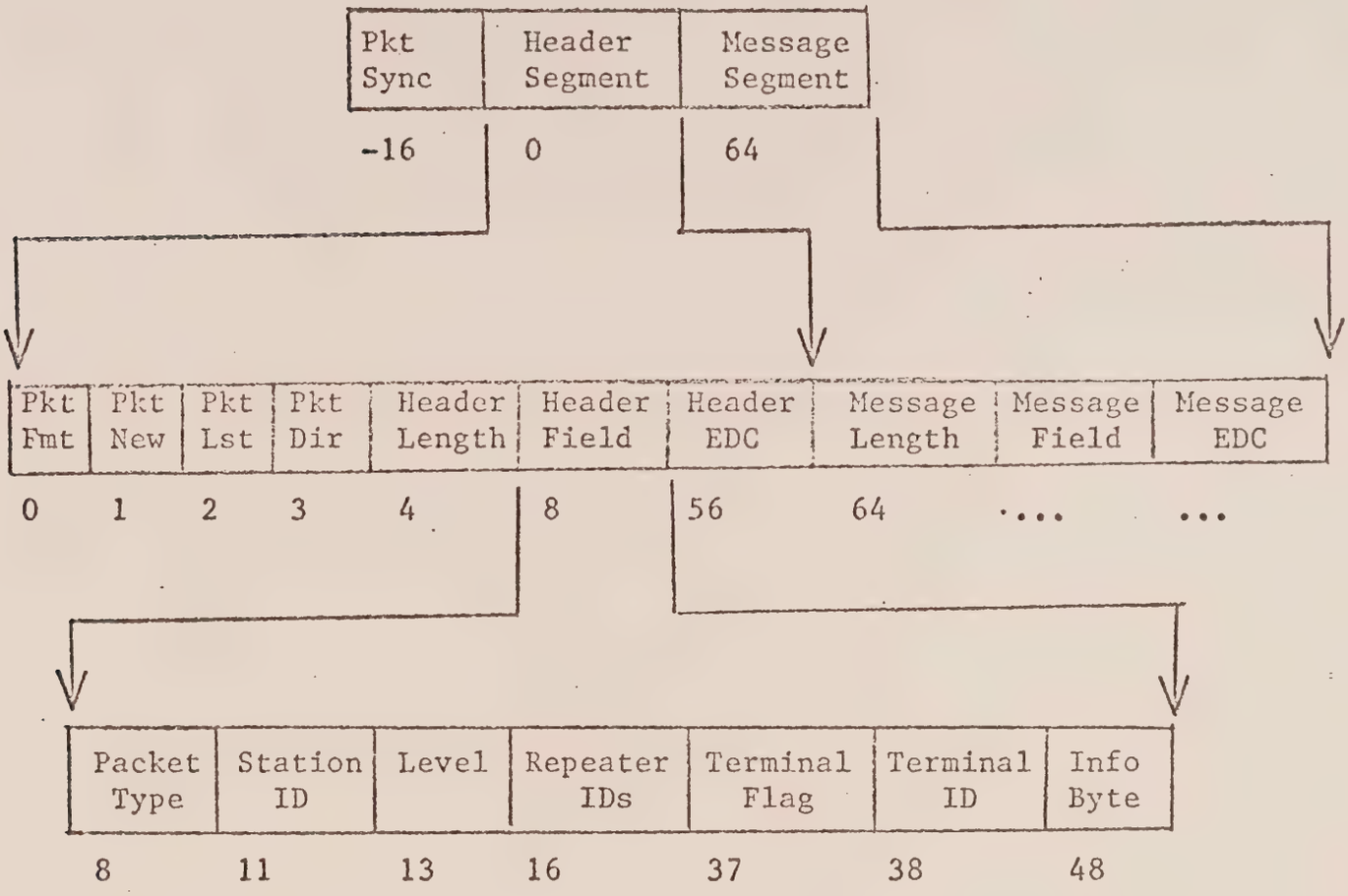


Figure 5. Measurement Packet Format

6. SUMMARY

This document describes the packet format proposed for use in the measurement program. By properly adjusting the length bits we can accommodate packets ranging in size from approximately sixteen (16) bits to over two thousand (2050) bits. Further, the format can be processed by a relatively general purpose interface which should not require extensive modification if the format is revised. It is still necessary

to consider acknowledgement requirements. In the event the (i+1)st transmission is accepted as an acknowledgment for the (i)th transmission, no unique acknowledgement formats are required. However, if a unique acknowledgement packet is desired, attempts should be made to eliminate the routing bits in those packets due to the large overhead in short packets.

Table 3 lists the specific bit interpretations for the packet planned for measurement experiments and will be used as an initial design specification for the hardware interface.

Table 3. BIT INTERPRETATIONS OF THE MEASUREMENT PACKET FORMAT

PACKET SYNC	=	A sixteen-bit field of '0000000000000001' for hardware synchronizing on the packet.
PACKET FORMAT	=	A one-bit field whose value indicates the format of the packet: 0 = header packet only 1 = header and message packet
PACKET NEW	=	A one-bit field whose value indicates that this packet is a new or re-transmitted packet.
PACKET LAST	=	A one-bit field whose value indicates that this packet is the last packet of a message: 0 = not last packet 1 = last packet of message
PACKET DIR	=	A one-bit field whose value indicates the transmission direction: 0 = from station 1 = to station
HEADER LENGTH	=	A four-bit field whose value describes the length in bytes of the header segment of the packet.
HEADER BITS	=	All those information bits that compose the header.
HEADER EDC	=	A variable length field whose value is the error detection code (EDC) of the header segment of the packet. This length may be 8 or 16 bits depending upon the magnitude of the HEADER LENGTH field.
MESSAGE LENGTH	=	An eight-bit field whose value describes the length in bytes of the message segment of the packet.
MESSAGE BITS	=	All those information bits that compose the packet.
MESSAGE EDC	=	A variable length field whose value is the error detection code (EDC) of the message segment of the packet. This length may be 16, 24, or 32 bits depending upon the magnitude of the MESSAGE LENGTH field.

Table 3. BIT INTERPRETATIONS OF THE MEASUREMENT ... (Con't)

The following fields are an expansion of the HEADER BITS field.

PACKET TYPE = A three-bit field whose value describes the type of packet being transmitted:
- 000 = text between terminal/station
- 001 = text between repeater/station
- 010 = control between terminal/station
- 011 = control between repeater/station
- 100 = undefined
- 101 = undefined
- 110 = acknowledgement of type NAK
- 111 = acknowledgement of type ACK

PACKET LEVEL = A three-bit field whose value describes the depth of the packet in the repeater network at a specific point in time:
- 000 = station level
- 001-111 = repeater level

STATION ID = A two-bit field whose value describes the station address:
- 00-10 = station number
- 11 = any station (broadcast)

REPEATER ID = A sequence of seven fields of three-bits each whose value describes the subaddress of a repeater within its hierarchical level:
- 000 = undefined
- 001-110 = repeater number
- 111 = any repeater (broadcast)

TERMINAL FLAG = A one-bit field whose value describes the packet is being addressed to a terminal at a given level and not a repeater at that same level:
- 0 = repeater at given level
- 1 = terminal at given level

TERMINAL ID = A ten-bit field whose value describes the absolute identification of a terminal.
- 0000000000-1111111110 = terminal ID
- 1111111111 = any terminal

INFO BYTE = An eight-bit field whose interpretation varies with the type of packet being sent:

TYPE	USE
000/001	= a text character
010/011	= a control character